

A Failure to Lunch: Nutrition in the Martian Mission

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“The Earth is the cradle of humanity, but mankind cannot stay in the cradle forever.”

—Konstantin Tsiolkovsky

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Problem Research

In a century of rapid technological modernization, the probability that humanity will become a multi-planetary species has become increasingly likely. Initiatives have been made by multiple companies and organizations to develop a suitable crew and spaceship that are equipped to handle said journeys. One of these companies vying for their position in space flight is Space Exploration Technologies Corporation, or SpaceX. Founded in 2002 by technology magnate Elon Musk, SpaceX has been partially responsible for re-igniting modern-day interest in extraterrestrial manned flight (SpaceX, 2020). Most of the research conducted within this paper revolves around estimates and measurements that were obtained with the express intention of producing a model-oriented around their plan to produce the first space colony.

The Plan and The Planet

A nutritional assessment of the needs of the crewmembers requires the use of a plan: the foundation for all the subsequent calculations. The plan is broken up into two parts. The initial phase of the plan involves landing twelve people on the surface of Mars. This group serves the pivotal function of setting up the colony's infrastructure for receiving the waves of around 100 to 200 astronauts who will arrive every 26 months (Schulze-Makuch, 2019). The vessel that SpaceX intends to use to carry out the mission is aptly named the Starship and has the capacity to carry up to either 100 people or 100 tons of cargo at a time (SpaceX, 2020). These ships will have to traverse a distance that is on average 225 million kilometers (140 million miles) in length (Ahmed & Aubourg, 2021). In between those millions of kilometers lies the possibility of disaster, which is why great care is taken to prepare the crew for any obstacles they may face.

The Risks of Space Flight

Being that the rotation of the crew is to occur roughly every two years, the crew of astronauts that embark on this voyage would have to be capable of withstanding the type of environment that a prolonged space flight will offer. An article published by the National Aeronautics and Space Administration (NASA, 2019) details a long list of the adverse health effects that astronauts are to experience during mid-flight:

Astronauts have higher radiation exposure, higher atmospheric levels of carbon dioxide, low humidity, and microgravity, which can all have effects on their health. ... These can have short-term consequences on multiple things, such as mood and performance, and kidney stone risk; and raises long-term concerns, such as bone and muscle loss, cardiovascular degradation, impairment of the immune function, and vision changes.

One otherwise common concern of space travel would be radiation. However, a group of researchers found that radiation does not impact the overall performance of organisms in space (Whoolery et al., 2020). Nonetheless, these challenges require that every facet of the journey be designed to accommodate and mitigate these shortcomings for the sake of crew's well-being. Possible remedies to some of the aforementioned ill-effects will be investigated within the *Thesis Defense* section of the paper.

Production Methods

There has been a myriad of projects that have sought to address the problem. Science journalist Charles Q. Choi (2019) wrote an article documenting researchers in Antarctica and their effort to produce a farming system that can feasibly be implemented within the shuttle of future space missions. Titled the EDEN ISS, the project is attempting to prove that novel farming

techniques such as aeroponic farming, a subset of hydroponic farming, are capable of handling a novel world. The research group is also considering cricket farming to gain a better perspective on the entire range of possibilities of food production.

Aeroponic farming is a farming technique where plants are suspended in the air within a climate-controlled, artificially lit room. The plants are fed a solution that contains the nutrients that are required to keep them alive. The benefits of this method for space applications are quite apparent: creating the most optimal food production environment in a confined space cabin is not all difficult. Implementing this process provides the capsule with an integrated carbon dioxide scrubber, humidity room, and another source of nutrition that does not require packaging. Additionally, the food that is produced will maintain a similar texture to that of food grown on Earth, making it easier for astronauts to acclimatize to a spaceship lifestyle.

Cricket Farming

Cricket farming was a food source whose potential was considered for the scope of this paper. As was outlined in a 2012 paper by Arnold van Huis, crickets were found to be 80% edible by mass as opposed to chickens, which were only 55% edible by mass (van Huis, 2013). Another body of work showed that crickets themselves had the highest protein content to kilogram ratio of all meats (Finke, 2002). When applied to the group pressurized cabin setting of the Starship, the cricket showed potential. The insect's small form factor allows for mass production in a small space.

There are, however, two main drawbacks. The nutritional drawback of crickets is their high iron content (Mwangi, 2018). In most cases, iron is a healthy nutrient, but astronauts must minimize iron consumption so as not to hasten the rate of bone loss. Research on the concerns of iron consumption was incorporated under the *Meal Plan* section of the paper. The crew's potential dissatisfaction with consumption of crickets is the other drawback, as crickets have not yet become an acceptable dish within the public's eye. If consumption were forced, crickets would lower team morale and pose a greater waste of resources.

Hydroponic Farming

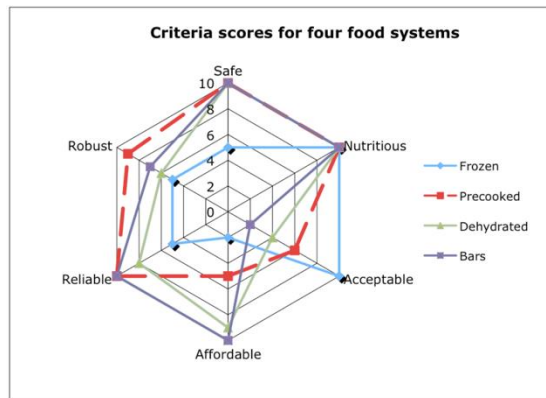
Howard Resh's book on hydroponics defines it as "the science of growing plants without the use of soil, but the use of an inert medium..." (Resh, 2013) In practice this means that hydroponics involves planting plants within different substrates and given a steady stream of nutrient rich water (*Hydroponics*, 2018). The research group opted to investigate the subset of hydroponics that required the least amount of water as it appear to be the better alternative when accounting variables such as space requirement and evaporation. This led to an investigation on the merits of an aeroponics system in a context of a space shuttle.

Aeroponic Farming

Aeroponic farming is a subset of hydroponics where the plants are suspended in the air and fed a solution that contains the nutrients that are required to keep them alive (Miller, 2020). The benefits of this method for space applications are quite apparent: creating the most optimal food production environment in a confined space cabin is not all difficult. Implementing this process provides the capsule with an integrated carbon dioxide scrubber, humidity room, and another source of nutrition that does not require packaging. Additionally, the food that is produced will maintain a similar texture to that of food grown on Earth, making it easier for astronauts to acclimatize to a spaceship lifestyle.

The most obvious drawback of aeroponic farming is the dependency on power. Plants have to be constantly watered to prevent roots from drying out (Miller, 2020). This presents an obvious challenge for space or another planet. A spaceship's power must first and foremost be used for the spaceship's systems meaning that in the event the spaceship experiences a power surge, the ship will prioritize its systems. This increases the likelihood that the crops will fail on the mission which makes this food source not completely dependable. Meanwhile, Mars will not immediately have infrastructure complex enough to power the expedition and then some.

The Compromise



Jones 2018

Figure 1

A research paper by Harry W. Jones, titled *Hydrated Food Should Be Used on Long Space Missions*, investigated all possible methods of astronaut nourishment that NASA had at its disposal. Jones (2018) investigated all possible methods of astronaut nourishment that NASA had at its disposal. Future food concepts for space included ready-to-eat meals (MREs), camping food, synthesized food, food produced in space, food bars, and others. The paper went into definitive detail to describe the merits of each possible food, as well as the disadvantages that prevented their adoptions. Regarding the onboard production of food, Jones (2006) fully investigates the merits of equipping a crew with the likes of such a support system.

The conclusion he drew rejected the notion of onboard farming on the basis that it was not worth the cost of its deployment. The best food option available to astronauts, as concluded by the paper, was precooked foods (*see Figure 1*)—most notably MREs. Hydrated foods appeared to perform nicely across all the criteria of the study. The only drawback associated with this option is the cost. Water is required for an MRE, but adds a considerable amount of weight, and therefore, cost. In its 2018 Falcon Heavy launch, SpaceX was able to achieve the cheapest payload-to-cost ratio in spacecraft history (Roberts, 2020). This renders precooked, hydrated food, as the best option of food that is going to be used to feed astronauts as they travel to the Mars. Methods of cutting water costs is further explored in the section of the paper titled *Water*.

Later analysis on the EDEN ISS yielded a conclusion the aligned with the opinion of the paper, as the amount of food produced by the system did not justify its weight nor cost when replacing it with stored food. The information concerning the EDEN ISS's production is further explored within the *EDEN ISS* section of the paper. Although the production methods outlined here are incapable of first-flight application, they most definitely will prove useful once their capabilities are developed to an extent that justifies their incorporation into a colony logistical framework.

Flight Crew

The appetite for space exploration is unparalleled, which is why NASA implements specific criteria to select their astronauts. The applicant must have a bachelor's degree in a select science, technology, engineering, or math (STEM) subject and have three years of professional work experience or 1,000 hours of pilot-in-command flight time to match. Additionally, it is encouraged that applicants have a master's or doctorate degree in their field of study; a

background that ranges from management to education to aviation; or experience serving in the military. Even then, there are roughly 4,000 applicants to become astronauts, but only 20 are selected, a 0.5% acceptance rate (Bray, 2015). Regardless, what is consistent amongst all the qualifications is that the astronauts themselves have to be mentally prepared for the isolation that is to occur on the transit to Mars.

Biosphere 2

In the 1990s, John P. Allen designed an experiment which would become a national phenomenon: The Biosphere 2 (Rose, 2020). The idea was to replicate an environment that would prove the feasibility of having humans live in a Martian facility. The experiment was designed and built off of years of experience that Allen had researching and living in different ecosystems around the world. Due to the popularity of it at the time, Allen wanted to prove that people could one day thrive in space. The facility encompassed many facets that would be included in outer space travel, such as plant cultivation and a heavy reliance on cooperation, to make the expedition run smoothly. However, it was soon discovered that the facility did not possess the capability to create an optimal living environment for the crew.

According to team reports, there were too few calories to sustain the daily requirement. Oxygen levels within the compound had fallen to 14.2% as opposed to the normal 21%, which caused a lot of strain on the crew. The team was mainly composed of laypeople, and as such, was not prepared for such a harsh setting. The adversity and situation alone caused the group to grow cold towards one another. This social climate also fostered division among the team, as each faction had different suggestions on how they would want to go about rectifying the situation.

All of this serves as a reflection point for the potential crew. Being some 225 million kilometers from Earth and 20 minutes from a response from Johnson Space Center in Houston means that will mainly be left to their own devices. The team must possess a dynamic resilient to many obstacles: their survival will depend upon it.

HI-SEAS V

The same idea of researching conflict within an isolated group setting was echoed in modern iterations of the Biosphere experiment. A series of projects conducted in Hawai'i under the collective name Space Exploration Analog and Simulation (aptly abbreviated HI-SEAS) primarily focused on group collaboration. The test subjects used in the HI-SEAS trials were vetted by NASA, contributing specialized knowledge and experience to the experiment (Associated Press, 2017). The HI-SEAS V experiment in particular was designed to measure the hindrance of performance due to poor team cohesion (HI-SEAS Missions I – VI). The group they utilized was made up of six people: four men and two women. This gender balance bore similarities to data that the research group examined regarding astronaut admissions from 1995-2009: approximately 23% of astronauts that graduated within the specified years were women (NASA, 2017). The background of the participants also closely resembled the educational background of the astronauts that graduated from 1995-2021. Within the data, the research group found that there had been a major emphasis placed on engineering with roughly 50% of male astronauts having a major in the field. The physics background applicants were not demonstrated within this data sample of people; nonetheless, this group background does mirror a type of composition that we will likely see within the groups of astronauts that are sent to space.

Ansley Barnard was a member engineer on HI-SEAS. In her University of Washington interview (as cited in Yates, 2017) on the topic, she recounts the experiences that she believed best equipped her for participating within a Martian-like setting:

At the UW, I also worked at the [university's] Kirsten Wind Tunnel (UWAL [University of Washington Aeronautical Lab]). A large portion of an astronaut's work boils down to operations skills. You have to execute a plan, adjust to new information, and stay on good terms with your crew. Working in the UWAL environment prepared me well for HI-SEAS.

Barnard's experience indicates that astronaut selection should reflect the candidates' work and collaborative experience. The group on board the Starship will be comprised of teamwork that the team will require. The group on board the Starship will be comprised level of teamwork that the team will require. The Starship Shuttle is going to include a myriad of people who have a plethora of experiences that can be of service to the crew. Experiences mirroring that of Barnard's, where the applicant has to deal with multiple groups on a frequent basis, should serve as a basic requirement for astronaut recruitment of this mission.

Food

Properly assessing and administering nutrition for the crew is a major concern of spaceship travel. Texas A&M University nutritional physiologist Nancy Turner laments, "We still know only a small amount about the nutrient requirements to promote health even for those of us living normal lives here on Earth" (Choi, 2016). It is one of the aspects of a journey that appears to be taken for granted yet bears significant consequences for the well-being of astronauts. Many scientists have continued research into this area of space logistics to determine the drawbacks that must be addressed to combat the ill-side effects that can occur from prolonged low-gravity exposure.

In Flight

Currently, astronauts aboard the International Space Station (ISS) are fed three meals a day, with snacks, which repeat weekly (NASA, 2004). These meals are going to have to rely on a mixture of locally produced food and stored food to fulfill the nutritional requirement to sustain themselves for the length of the trip. This sort of plan requires leveraging research related to the production of food items in sub-optimal climate zones as well as the lengthening of the preservation of said food items.

A paper studying the modern preservation capabilities of food stored on the ISS found that most food used on the ISS was ill-suited for long-distance space travel (Catauro & Perchonok, 2012). About 75% of the thermostabilized food on the ISS can last for 2 years and 50% can last for more than three at maximum according to the source. The longer the food last the less nutritious it becomes. The longer the food lasts the less nutritious it becomes. The same article recommended further research into refrigeration technologies as it would improve the shelf life of many of these food items.

The EDEN ISS

Per the report *Biomass Production of the EDEN ISS Space Greenhouse in Antarctica During the 2018 Experiment Phase*, the researchers who opted to initialize the greenhouse project had chosen a specific list of plants to measure.

Category	Plants
Lettuce	Batavia, Expertise, Outredgeous, Waldmann's Green
Leafy Greens	Red Mustard, Swiss Chard, Arugula, Mizuna
Herbs	Basil, Chives, Parsley
Fruit	Red Dwarf Tomato, Orange Dwarf Tomato, Cucumber
Tuber	Radish, Kohlrabi
Miscellaneous	Tomatoes, Pepper (Variety), Cilantro, Mint, Lemon Balm, Celery, Strawberry

Zabel, P. (2020)

Table 1

The data produced by the project was analyzed by the research group to estimate the EDEN ISS monthly kcal production rate. Following these calculations, the research group was able to estimate that the greenhouse produced 7370 kcal produced per month. This production rate pales in comparison to the 1,050,000-kcal consumed per month by the crew calculated by Equation 4. Since the production rate only made-up 0.7% of the actual consumption rate, the group decided, as stated before, to reject the possibility of including this production method within the inflight calculations until the technology was further developed.

Martian Farming

Martian soil is known to carry toxic heavy metals (Crowley, 2016), as well as perchlorates (Plumer et al., 2017); however, it is possible to remove those toxic compounds from the Martian regolith and convert it into the soil for farming. An article published within the science journal *Chemosphere* explores a way to remove perchlorates from contaminated soil (Nair et al., 2020). In order to be successful, these separation schemes will need to be conducted on a large scale to produce enough material for traditional farming. The other concern is that Mars contains little, if any, organic matter—hence the usage of the term regolith as opposed to soil. Organic matter is required for plant growth. The immediate focus should be on alternative farming methods, specifically ones that are less dependent on soil.

Water

Water is an essential component of life, required for plants and animals alike. It is the structure behind cells and the main method of transport for other nutrients to flow. Not only would a lack of water be fatal to the astronauts, but would prevent any hope for growing food, making starvation for the astronauts a possibility. However, at 1 kg/L, water is heavy and will take away valuable storage space from the ship.

Synthesis

Currently, on the International Space Station (ISS), water for astronauts is synthesized with hydrogen (H₂) and oxygen (O₂) gases (Dunnill, 2018). This is certainly a possibility during spaceflight and on Mars but carrying enough hydrogen and oxygen will be difficult to store. As gases, both will need to be stored in elaborate tanks to mitigate leakage into either Earth's

atmosphere or the vacuum of space. As liquids, both will need to be stored at extremely low temperatures, which would require a lot of energy.

Urine Reclamation

Perhaps the most obvious solution during spaceflight is recycling astronaut urine. The first major technology was developed in 2009, when the ISS started processing urine the machine, named the self-explanatory Urine Processor Assembly (UPA). A major improvement occurred in 2016, NASA announced that they have developed a chemical solution called Alternate Urine Pretreatment, which assists the ship's Water Reclamation System in reclaiming a greater percentage of potable water from urine (Mathewson, 2016).

Water on the Red Planet

Water on Mars would seem to be the most obvious source for astronauts upon landing. In 2018 and 2020, researchers used a special type of radar to search for water, finding what appeared to be a lake beneath the planet's surface (O'Callaghan, 2020). What is inside, however, is a topic of debate.

The possibility of the lakes containing liquid water on a cold planet such as Mars would require that the water has a high salt content. The water would have to be upwards of 20 times as salty as seawater, salt levels that would not be suitable for most life (O'Callaghan, 2020). The way to combat this is through desalination processes, similar to preparing drinking water from seawater.

Other scientists, meanwhile, debate the existence of liquid water at all, suggesting that the Martian water is instead in the form of ice (O'Callaghan, 2020). For the astronauts to tap into this resource, they would have to cut ice blocks for themselves and heat it up, which requires plenty of energy.

Career Research

Throughout the process of investigating the interdisciplinary subjects of astronomy, space exploration, and nutrition, the research team had encountered many notable figures whose research provided valuable insights. Given that these scientists were studying a topic that relied on measurement, it goes without saying that they have utilized concepts from various sources, including math and statistics, to conduct their research.

Lucie Poulet

Lucie Poulet is currently a postdoctoral fellow at NASA Kennedy Space Center. As a Ph.D. student in France, she developed mechanistic models to understand plant growth in reduced gravity environments for an application in bioregenerative life-support systems (Poulet et al., 2018). Nowadays, her work involves focusing on modeling gas exchange phenomena in plants, therefore, she's concentrated on food production in space. Moreover, she's focusing on developing physical models to understand plant growth in reduced gravity environments as she did when she was a student.

Poulet was a crew member of four Mars analog missions. She was part of a four-month NASA-funded mission in the HI-SEAS, where she and the rest of her crew performed high-fidelity geological fieldwork. The goal of the four-month mission was to study crew performance and interaction in long-term isolation, and her role in the mission was crew scientist.

Additionally, she was part of two separate two-week missions in the Mars Society Utah Mars Desert Research Station. Her fourth mission was a two-week mission at the Lunares

Habitat in Poland. She has over ten years of experience with regenerative life-support systems across different space agencies. Furthermore, Poulet had multiple years of volunteer experience, where she had many roles and made several contributions. She not only promoted the exploration of Mars to the broad public, but also promoted the space sector and the Space Generation Advisory Council. In her volunteering roles, Lucie also organized space-related events with space experts and even secured partnerships with companies and organizations for the second European Space Generation Workshop.

She worked as an Aerospace Engineer and Research Associate for the German Aerospace Center for almost two years. Had she worked in the United States, she would have had a salary of about \$116,500 per year, the 2019 median pay for an aerospace engineer according to the Bureau of Labor Statistics (*Aerospace Engineers*, 2020).

James Arthur Harris

James Arthur Harris was a botanist and biometrician born in Ohio in 1880. He finished his undergraduate studies in biology at the University of Kansas by 1901. As an undergraduate he was assigned a research problem of determining whether the gonads of the dimorphous crayfishes of the region showed characteristic differences. His successful work resulted in the publication of four systematic papers on crayfish. After graduating, he taught botany at the University of Kansas summer school.

Harris was known not only to have made major contributions in many fields, but also to have developed the Harris-Benedict equation with Francis Gano Benedict in 1918. The equation is an easy-to-use method widely utilized to predict and estimate a person's basal metabolic rate (BMR) and daily calorie requirements. These formulae paved the way for discovering the nutrition and hydration necessary for a person to maintain full physiologic function. Doctors could now provide the nutrients by aqueous solution known as Total Parenteral Nutrition (TPN) and administer it intravenously. The solution is used multiple times in many post-surgery and oncological treatments where the person has digestive issues or cannot process foods normally.

The daily requirement for the human body is well known, and the standard protocol for calculating the dosage is to use the Harris-Benedict Equation with additional adjustments for individual activity level and stress environment. The HBE estimates the basal metabolic rate and daily kilocalories needed and is a function of gender, body weight, and body height, therefore, the result calculated is used to keep a crew's current body weight in space.

Years after the Benedict-Harris equation was developed, Harris was awarded the Weldon Memorial Prize and Medal by the University of Oxford, the most prestigious award in the field of biology. His papers contributed to scientific journals, number more than three hundred titles and included topics about almost every field of the biological sciences. In addition to that, he was elected president of the American Society of Naturalists in 1926, and he served as a member of the Division of Biology and Agriculture of the National Research Council in 1930, the year he died.

Considering his extensive research in biochemistry, agriculture, and botany, he most closely fits the description of a soil and plant scientist. According to the United States Bureau of Labor Statistics, this occupation has a mean annual wage of about \$69,170, (*Occupational Employment*, 2020).

Mathematical Model

The mathematical components used within this paper demonstrate simple yet grounded methods of predicting the Martian team's future necessities. Care was taken to differentiate

between the different conversion rates between both the imperial and metric system. For the sake of simplification, this paper is to provide all of its findings in SI units as they are more widely accepted within the academic world and are consistent across measurements.

Harris-Benedict Equation

The research team sought a model that could reliably estimate the conditions of caloric requirements of the crew. These caloric estimations would then be utilized to construct nutritional baselines and overall meal plan ingredient compositions that could prevent the crew from acquiring any nutritional deficiencies. After some research, the research group opted to incorporate the Harris-Benedict Equation to suit this need. The equations were first published in 1919 as a method for determining an individual's basal energy expenditure based on their activity level.

Basal metabolic rate (BMR) is a measurement of energy expenditure (kilocalories) per unit time (24 hours). The Harris-Benedict Equations use an individual's BMR and his or her level of activity to estimate his or her own energy expenditure. This energy expenditure projection can be used to approximate the nutrition requirements that the crew is to require for the duration of the journey. The formula for calculating the energy expenditure of any one individual is as follows:

$$\text{Men: } EER = 662 - (9.53 \times \text{age}[y]) + PA \times [(15.91 \times \{\text{weight}\}[kg]) + (539.6 \times \{\text{height}\}[m])]$$

$$\text{Women: } EER = 354 - (6.91 \times \text{age}[y]) + PA \times [(9.36 \times \{\text{weight}\}[kg]) + (726 \times \{\text{height}\}[m])]$$

Equation 1

This is the same model that is used by NASA to measure their astronaut's nutritional requirements (NASA, 2004). The possible range of physical activity (PA) values indicate the activity level of the astronauts (*see Table 7*). The research group opted to evaluate astronauts using values of a higher activity level, as the main dietary focus will be to preserve—if not grow—muscle. We incorporated these insights into our calculations concerning crew caloric intake to provide the rate of food consumption onboard the shuttle.

The Model

The model utilized to formulate this paper's conclusions was centered around the rate of consumption of the crew in kilocalories per month of deployment. The rationale behind this choice was that it allowed the research group to easily incorporate data into a model that was fairly intelligible, and which offered insight into the group's most pertinent questions. The function was determined to better suited analyzing a constant rate of decrease since there weren't many factors that could cause the consumption or production rate to fluctuate much in space. This perspective fostered the following equation:

$$C = (P - M)(t_i) + C_0$$

Equation 2

This function describes the number of available calories that are onboard the Starship for a certain number of months after launch (t_i) assuming a constant rate of production and an average rate of consumption. The initial number of kilocalories stored onboard for the flight (C_0) is unknown and serves as one of the variables that the research group was attempting to solve

for. The difference between the rate of food production ($P(n_i)$) and the rate of food consumption by the crew ($M_i(n_i)$) was integrated to demonstrate the number of calories that would need to be consumed from the stored food supply.

This model provided more unknown variables that required further subsequent modeling. More specifically, the variables regarding the rate of production and consumption, as was stated before, were not modeled to reflect a linear rate; therefore, new models had to be introduced to work in conjunction with the previous model to generate clear results. First, the production model was addressed because it was the variable within the equation that involves the most speculation:

$$P = \sum r_l(x_l)$$

Equation 3

This equation defines the agricultural output on the station as the sum of all the rates of calories production in terms of kilocalories per month per plant variety l (r_l) times the number of said plants within the onboard greenhouse (x_l). This equation was used to generate the values (see *Table 7, appendix*) that substantiated our rejection of an aeroponic system as outlined under *The Compromise*.

Next, the consumption model was developed to best gauge how many kilocalories would be required to send a group of twelve people into space for around six months. The sum of the kilocalorie requirement for that would suffice to calculate the overall consumption rate of the crew of the Starship for any given month. This is written as:

$$M = \frac{\sum_{n=0}^{n_f} M_{p_n}}{n_f}$$

Equation 4

The model shows that the crew consumption for any given month is the sum of all the crew members' kilocalorie requirements for all months within the range (M_{p_n}) divided by the number of months. We can refer back to the aforementioned Harris-Benedict Model to calculate the alluded kilocalorie requirements; before we can do so, however, we first have to gain a good understanding of the anatomy composition of all crew members on board. For this part, the research group resorted to a general approximation of the weights and height of astronauts. This approximation was based on the previous fact that most astronauts in history had military backgrounds. Determining the average height and weight measurements of astronauts required the research group to randomize the height and weight of each crew member between a range of realistic values. These randomized values were then used to approximate the EER requirements of a crew.

This model only accounts for the caloric intake of the astronauts: cost and nutritional requirements will be further explored under the *Meal Plan* section of the *Thesis Defense*.

Thesis Defense

Astronaut Roll Call

As a basis for the positions, the paper is going to utilize the STS-113 spaceflight mission. The mission was carried out by a ten-person crew and its purpose was to attach a radiator module

to the side of the ISS (NASA, 2003). The roles were altered, a varying degree, to reflect the change in the purpose of the mission.

Role	Experience
Commander	- Has served in many leadership positions - Can address difficult situations as they arise - Military experience
Pilot (second-in-Command)	- Has flown fighter jets for the military - Has a high number of flight hours - Older age range (>38 yrs. old) - Education: Aviation Engineering
Co-Pilot	- Has the second highest number of flight hours - Has flown for the military - One of the younger people in the crew - Education: Aviation Engineering
Chief Technical Engineer	- In charge of coordinating and maintaining all electronics-based equipment - Aid in the development the Martian base when the crew arrives - Most experience working with space equipment - Education: Electrical Engineering
Technical Engineer	- Reports to the chief Technical Engineer - Maintains electrical equipment - Education: Electrical Engineering
Technical Engineer	- Reports to the chief Technical Engineer - Maintains electrical equipment - Education: Electrical Engineering
Geology Specialist	- Perform tests on Martian soil - Begin exploring for subsurface terrain structures (caverns) - Education: Geology, Earth Sciences
Payload Specialist	- Manages the supplies of the crew - Coordinates with NASA to relay information on shipments - Aids the construction specialist in initiating the Martian base framework - Education: Engineering, Mathematics, Physics
Chief Biologist Specialist	- Conducts test in-flight tests on organic matter - Aids in the initialization of Mars' food production - Education: Biology
Biologist Specialist	- Reports to the chief biologist - Conducts in-flight tests on organic matter - Aids in the initialization of Mars' food production - Education: Biology
Medical Specialist	- Facilitates the development of the Martian's base's medical capabilities - Runs tests on the crew of the mission for the duration of the story - Education: Field Medicine
Construction Specialist	- Coordinates the construction of the initial part of the facility - Works with other specialists to assure that the base built properly - Education: Structural Engineering

Table 2

Cargo Cross-Check

As was referenced in the section of the paper dealing with the specifications of the Starship, the plan is going to require that all the equipment, food, and crew members fit within the maximum allotment of weight capacity for the trip which has been calculated to be 100 tons of weight. An article by Remy Melina (2017) stated that four tons (3630 kg) of food was required to sustain a crew of three for about six months on the ISS (Melina, 2017). Being that the

crew of the Starship is 12 people, we can predict, based on this estimate, that the Starship will require ~16 tons (14,515 kg) of food (accounting for packaging) to last the crew the length of the journey until they can resupply on the surface of Mars. The 16-ton requirement of food entails that the crew aboard the Starship would have ~84 tons of that weight would be dedicated to the equipment, living space, greenhouse, and other items necessary to successfully carry out the plan.

Item	Weight on Earth (ton)
Food Storage	16
Crew	1
Onboard Equipment	20
Mars Equipment	63
Total	100 tons

Table 3

This portion of the research is dedicated around sending the initial number of astronauts to the surface of Mars. In order to gauge the amount of food that the astronauts are going to be receiving, the research group is going to assume that the nutritional content of the food on Mars has not decreased as a result of the time it spent waiting.

Meal Plan

For the duration of the mission to Mars, astronauts are going to have to subsist on a diet composition that reflects the multitude of systems that they have on board. The paper’s models create the threshold by which we will orient the meal plan. The Dietary Reference Intake reports the healthy ranges of macronutrients for an adult (see Table 4).

Macronutrient	AMDR (as percent of energy) ¹		
	Children 1-3 y	Children 4-18 y	Adults
Fat	30-40	25-35	20-35
<i>n</i> -6 polyunsaturated fatty acids ² (linoleic acid)	5-10	5-10	5-10
<i>n</i> -3 polyunsaturated fatty acids ² (α-linolenic acid)	0.6-1.2	0.6-1.2	0.6-1.2
Carbohydrate	45-65	45-65	45-65
Protein	5-20	10-30	10-35

Additional Macronutrient Recommendations	
Macronutrient	Recommendation
Dietary cholesterol	As low as possible while consuming a nutritionally adequate diet
Trans fatty acids	As low as possible while consuming a nutritionally adequate diet
Saturated fatty acids	As low as possible while consuming a nutritionally adequate diet
Added sugars	Limit to a maximal intake of no more than 25 percent total energy ³

¹AMDR = Acceptable Macronutrient Distribution Range. This is the percent of energy intake that is associated with reduced risk of chronic disease, yet provides adequate amounts of essential nutrients.
² Approximately 10 percent of the total can come from longer-chain *n*-3 or *n*-6 fatty acids.
³ Not a recommended intake. A daily intake of added sugars that individuals should aim for to achieve a healthful diet was not set.

Otten, J.J, Hellwig, J. P. & Meyers, L. D. (2006)

Table 4

For the sake of simplifying calculations, the research group opted to consolidate the macronutrient ratios into a specific set of ratios that followed the guidelines: 45% carbohydrates, 35% protein, and 20% fat. This diet composition leans more heavily in the direction of protein consumption. This was a conscious decision by the research group as a higher protein diet has the potential to mitigate muscle loss (Mettler et al., 2010). The paper, unlike the Dietary Reference Intake, will not make a discrepancy between fats and fatty acids (see Table 4). As was discussed in *The Risks of Space Flight* section, the astronauts have to contend with multiple health risks that can lead to long-term adverse health effects. The meal plan that is proposed should, at best, address these shortcomings and, at least, mitigate them.

The first nutritional issue that NASA has to address with about its astronauts is the presence iron within the body. A study published within the National Library of Medicine’s web page detailed an increased occurrence of body iron content and Serum ferritin along with a decrease in transferrin (Zwart et al., 2013) in early space flight. Serum ferritin is a protein that is responsible for storing iron (Nall, 2020) until it’s taken to areas within the body by transferrin (Shiel, Jr., 2018) where it is used to create red blood cells. A low transferrin level, as was described by the study, can induce anemia (Shiel, Jr., 2018) or

hemochromatosis (Lockett, 2018) as the red blood cells are not able to access said iron for mitosis. An Eater article (Preston, 2015) details a possible avenue of reproach that scientists are investigating which entails the consumption of seafood.

The same article includes notes on other apparent nutrient deficiencies and adverse health effects that astronauts experience within space, such as a lack of Vitamin B₁₂ and a degradation of vision (Preston, 2015). Certain foods that supply a fair amount of Vitamin B₁₂ include low-fat yogurt, low-fat milk, salmon, fruit juice, spreads, and others (Richards, 2020). These foods can be incorporated within the meal plan we consume on a regular basis to incur the various benefits that B₁₂ has to offer to the astronauts. As for the vision loss, scientists, for some time, have believed that one possible cause leading to the deterioration of eyesight within astronauts is a pressure imbalance within the cabin as a result of slight changes in the air composition (Keith, 2012). Recently, John Berdahl, a well-renowned ophthalmologist, has been working closely with a group of scientists to produce a set of goggles that they believe can help mitigate, if not eliminate, this issue (Gopal, 2017).

Currently, those within spacecraft have to get their vitamin D from supplements being that they are shielded from the radiation that is used to produce Vitamin D. There is nothing to be done to improve this aspect of space travel as there is no alternative food source that can improve food consumption according to Sara Zwart, a food scientist at NASA (Choi, 2016). Although the astronauts are shielded from the useful radiation, they still experience harmful radiation as was mentioned in *The Risks of Space Flight* section. NASA has resorted to using a mixture of drugs and antioxidants to combat this issue (Frontiers, 2021).

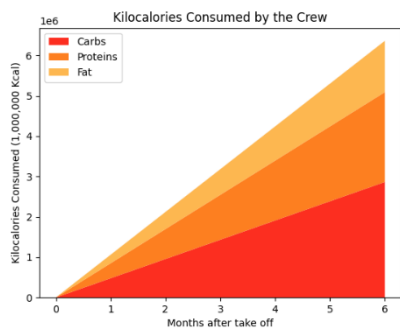


Figure 2

calculations have been made, the crew will require roughly 713.71 kg of carbohydrates, 475.81 kg of protein, and 176.22 kg of fat. The total mass of macronutrients that are needed for the transit alone is 1,365.74 kg (1.51 tons). This figure only accounts for the macronutrients and not the total weight of the actual food items let alone their packaging.

To create the meal plan, these values need to be distributed evenly into 11-day intervals which is the interval that NASA uses to create its meal plans (Jones, 2018). Since the launch is supposed to start on July 30, 2030, and take six months, the astronauts are going to be on Mars by Jan 30, 2031, which is 185 days of travel. Dividing 185 days by the 11-day intervals will reveal the crew will have 16.82 meal rotations before they touch down on Mars. The model will require that the 16.82 rotations be rounded up to 17 rotations giving the crew two extra days of food storage when they land which can buffer the time, they have to establish contact with the preceding shipment. Each crew member will require, on average, a daily intake of 318.03 g of

Using Equation 4 set forth under the mathematical section, the research group was able to produce a graph that reflected the proportion of macronutrients that crew would need to consume for the duration of their journey (see Figure 4). The calculations posited that the crew would require a total of 6,344,087.02 kilocalories (kcal) to sustain the crew for six months: 2,854,839.16 kcal from carbohydrates, 1,903,226.12 kcal from protein, and 1,586,021.75 kcal from fat. Using the Atwater factor conversion rate provided within the Dietary Reference Intake (see Table 6, appendix), the kcal from said macronutrients can be converted from energy expenditure to total mass needed from said nutrient. Once all the

carbohydrates, 214.33 g of protein, and 79.38 g of fat.

Since pre-cooked food is the best option according to *The Compromise* section of the paper, the meal plan will be based on regular foods with a focus placed on maximizing the number of proteins and antioxidants consumed. For this requirement, the research group resorted to food recommendations from websites such as Healthline (Gunnars, 2020), Cooking Light (Weg, 2018), and Gloriously Vegan Meals to Prep Everyday” (Wellness, 2018). The point of the mixing of the three sets of recommendations was to try to achieve a higher consumption rate of protein that could be offset by the amount of carbohydrates consumed. Inclusion of vegan meals was meant to offset the levels of iron acquired through the consumption of red meats and fish (Spritzler, 2020). Foods were also chosen for their antioxidant content (Raman, 2018). Antioxidants were included per Ryan Raman’s article “12 Healthy Foods High in Antioxidants” (Raman, 2018). The resulting compilation of cross-referenced recipes was recorded onto a table to display the information in a concise manner (*see Table 5*).

	Day 1	Day 2	Day 3	Day 4
Breakfast	Pancakes	Greek Yogurt with Berries and Honey	Banana Raisin Oatmeal	Eggs, Beans
Lunch	Hummus Veggie Wraps	Chickpea Spinach Salad	Mac and Cheese	Shawarma Bowls
Dinner	Pork Tenderloin, Salad	Pesto Pasta, Cut Potatoes	Cabbage Soup	Veggie Chili
	Day 5	Day 6	Day 7	Day 8
Breakfast	Breakfast Quinoa	Lentil Stew	Assorted Fruits	Breakfast Sausage, Hash Browns
Lunch	Potato Salad	Greek Slaw and Chicken Pita	Turkey Panini	Chicken Fiesta Salad
Dinner	Tuna, Couscous Salad	Green Frittata	Shrimp and Leek Spaghetti	Cauliflower Rice Burrito Bowls
	Day 9	Day 10	Day 11	Snacks
Breakfast	Mixed Berry Parfait	Breakfast Strawberry Smoothie	Crew Member’s Preference	- Trail Mix - Tortillas
Lunch	Corn and Potato Chowder	Tomato Barley Soup		
Dinner	Chicken Sandwich	Salmon, Kale Salad		

Table 5

Quinoa, Tuna, Turkey, and others were kept within the meal plan, despite the iron levels they produced, because they offered other nutrients, like fiber, which is needed by the crew.

Shipment Calorie Counts

According to these predictions, when the first humans step foot on Martian regolith, their food store is going to be mostly, if not completely, depleted. In order to keep them alive for the next shipment of food, which is to occur every 26 months, the shipment that precedes them on Mars would have to contain more than 27,551,463.62 kcal (see Figure 3). This number indicates the amount nutrition that they must consume. The real, initial number of calories that they would need to last the set time frame may be much greater. Going by the ISS estimations, outlined under the *Cargo Cross-Check* section of the paper, the crew would require ~69.33 tons of provisions.



Figure 3

Calculated Cost

The cost of take-off for the Starship would be around \$13,612,500 assuming the same Payload Cost to LEO as one of SpaceX's previous rockets, the Falcon Heavy, (Roberts, 2020), and the rocket was at its max capacity of 100 tons. This figure ignores the fuel cost associated with traveling into deep space as well as the cost of the cargo and equipment that is sent alongside the crew or the cost of development. For a more precise calculation of cost, we can resort to the cost estimate given by Musk. Sending people to Mars would cost \$10 billion per person according to an address Musk gave at the International Astronautical Congress in 2016 (Caughill, 2017). Added together, the full cost for a 12-person crew to travel to space would demand \$120 billion. This estimated cost does not insinuate the construction of a Martian base, let alone the projected hundreds upon hundreds who are expected to arrive at later dates. Musk reportedly has already assessed this situation and is expecting the cost of space travel to decrease once more organizations and companies enter the industry (Caughill, 2017).

Conclusion

Astronauts on their way to Mars will have to subsist on a diet of pre-cooked meals. These precooked meals will require water that is to be upcycled within the spaceship to lengthen the longevity of the water brought onboard. The food will most likely be stored in freezers large enough to store the capacity of food required to undertake the journey. This technology still needs to be researched and implemented before we can expect to see any considerable progress on the nutrition front. The food served on board the Starship will follow NASA's guidelines with what types of food they can bring onboard. These food items will supply plenty of grams of protein and carbohydrates to encourage muscle growth and off-set muscle loss. The food will also contain adequate levels of antioxidants to aid in the mitigation of radiation that the crew experiences while in transit. Vitamins B₁₂ and C will be supplied by the crew's diet, while other nutrients like vitamin D will be consumed in supplement form to prevent deficiencies. The presence of iron with the diet of astronauts will be minimized to prevent bone loss that occurs within low-gravity environments. All things considered, the journey to Mars will be just as much about food as it will be about rocket fuel—a failure to launch is just as much of an issue as a failure to lunch.

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Appendix

Macronutrient	Kcal/g ^a
Carbohydrate	4
Fat	9
Protein	4
Alcohol ^b	7

^a These values for carbohydrate, fat, protein, and alcohol are known as Atwater Factors. Atwater, a pioneer in the study of nutrients and metabolism, proposed the use of these values. They are often used in nutrient labeling and diet formulation.

^b The alcohol (ethanol) content of beverages is usually described in terms of percent by volume. One mL of alcohol weighs 0.789 g and provides 5.6 kcal/mL.

Table 6

TABLE 2 Physical Activity Coefficients (PA Values) for Use in EER Equations

	Sedentary (PAL* 1.0-1.39)	Low Active (PAL 1.4-1.59)	Active (PAL 1.6-1.89)	Very Active (PAL 1.9-2.5)
		Typical daily living activities PLUS 30-60 minutes of daily moderate activity (e.g., walking at 5-7 km/h)	Typical daily living activities PLUS at least 60 minutes of daily moderate activity	Typical daily living activities PLUS at least 60 minutes of daily moderate activity PLUS an additional 60 minutes of vigorous activity or 120 minutes of moderate activity
Boys 3-18 y	1.00	1.13	1.26	1.42
Girls 3-18 y	1.00	1.16	1.31	1.56
Men 19 y +	1.00	1.11	1.25	1.48
Women 19 y +	1.00	1.12	1.27	1.45

* PAL = Physical Activity Level.

Table 7

Vegetable	Amount Produced (in kg)	Mass of one vegetable	Calories of one vegetable	Calories produced in 2018	Calories produced per month
Cucumbers	67 kg	410 g = 0.410 kg	66 cal	(66/0.410)*(67kg) = 10,785	10,785/12 = 895 cal
Lettuces	56 kg	600 g = 0.6 kg	90 cal	(90/0.6)*50kg = 8,400 cal	8,400/12 = 700 cal
Tomatoes	50 kg	111g = 0.111 kg	20 cal	(20/0.111)*50kg = 9,009 cal	9,009/ 12 = 750 cal
Radish	8 kg	4.5 g = 0.0045 kg	1 cal	(1/0.0045)*8 = 1,777 cal	1,777 / 12 = 148 cal
Kohlrabi	19 kg	400 g = 0.4 kg	108 cal	(108/0.4)*19 = 5,130 cal	5,130 / 12 = 427 cal
					2,920 calories

Vegetable	Amount Produced in 2018 (in kg)	100g or 0.1kg of the vegetable in cal	Calories produced in 2018	Calories produced per month
12 kg Herbs	Basil 12 kg/3 = 4 kg	233 cal	(233/0.1)*4kg = 9,320 cal	9,320/12 = 776 cal
	Chives 12 kg/3 = 4 kg	30 cal	(30/0.1)*4kg = 1,200 cal	1,200/12 = 100 cal
	Parsley 12 kg/3 = 4 kg	36 cal	(36/0.1)*4kg = 1,440 cal	1,440 / 12 = 120 cal
Leafy Greens	Swiss Chard 49 kg/3 = 16.33 kg	19 cal	(19/0.1)*16.33kg = 3,103 cal	3,103/12 = 258 cal
	Red Mustard 49 kg/3 = 16.33 kg	200 cal	(200/0.1)*16.33kg = 32,660 cal	32,660/12 = 2722 cal
	Mizuna 49 kg/3 = 16.33 kg	35 cal	(35/0.1)*16.33kg = 5,715 cal	5,715/12 = 476 cal
				4452 calories

Total 2,920 + 4452 = 7,370 kcal

Table 8

Notes on Programming Tools

The Python and C++ programming languages were used to conduct the statistical analyses observed in this paper. The Python matplotlib.pyplot was used to generate the graphics and charts in this paper, known as Figure 3 and Figure 4. All team members contributed to the programs created in March 2021 for this project.

The multiple programs used for this project are included in the following GitHub repository: <https://github.com/talalzeini/srl>

The source code of these programs is also included below:

Program 1

```
# Python
# matplotlib.pyplot is used to visualize the graph
# Created March 2021
"""
crew_calculations.py: This program generates a plot of values that model the
calorie intake of the crew.
"""

# Imports
from AstronautsDataAnalysis import degree_random, height_random,
weight_random
from matplotlib.ticker import MaxNLocator, ScalarFormatter
import matplotlib.pyplot as plt
import numpy as np
import matplotlib
import random

# July 30 is the initial launch data according to wikipedia;
https://en.wikipedia.org/wiki/Mars_2020
days_per_month = {1: 32, 2: 28, 3: 31, 4: 30, 5: 31, 6: 30, 7: 31, 8: 31, 9:
30, 10: 31, 11: 30, 12: 31}
initial_month = 8

"""
The youngest astronaut to be in space was 32 years old and the average ages
of an astronaut in 2013 was 36 years old;
therefore, we can add the difference of 36 and 32 to 36 and get our upper
bound which in this case is 40. The randint
code will set a bounds of 32 to 39(controlling for older aged people).
"""

# Dimensions will be taken in SI units
class Person(object):

    def __init__(self, position_name):
        self.name = position_name
        self.age = random.randint(32, 40)
        self.sex = 'M' if (random.randint(0, 100) > 29) else 'F'
        self.education = degree_random(self.get_sex)
        self.height = height_random(self.get_sex)
        self.weight = weight_random(self.get_sex)
        self.detail = self.weight_detail

    # Get the sex of the crew member
    @property
```

```

def get_sex(self):
    return self.sex

# Get the age of the crew member
@property
def get_age(self):
    return self.age

# Get the education subject of the crew member
@property
def get_education(self):
    return self.education

# Get the height of the crew member(m)
@property
def get_height(self):
    return self.height

# Get the weight of the crew member(kg)
@property
def get_weight(self):
    return self.weight

# Get the BMI verbal estimate of the member
@property
def get_detail(self):
    return self.detail

# ERR Model; Procures caloric requirement per month for each individual
crew member
def nutrition_requirement(self, level, month):
    if self.get_sex == 'M':
        PA = 1.25 if level == "high" else 1.11 if level == "low" else
ValueError("Specify activity level")
        EER = 662 - (9.53 * self.get_age) + PA * (15.91 * self.get_weight
+ 539.6 * self.get_height)
    else:
        PA = 1.27 if level == "high" else 1.12 if level == "low" else
ValueError("Specify activity level")
        EER = 354 - (6.91 * self.get_age) + PA * (9.36 * self.get_weight
+ 726 * self.get_height)
    return days_per_month[((month + initial_month) % 12) + 1] * EER

# BMI function
def BMI(self):
    return (self.get_weight / pow(self.get_height, 2.5)) * 1.3

"""
# BMI comparison function
@property
def weight_detail(self):
    BMIValue = self.BMI()
    return "obese" if 30 >= BMIValue else "overweight" if BMIValue >= 25
else "normal weight" if BMIValue >= 18.5 \
    else "underweight" if BMIValue < 18.5 else None
"""

# Generate 12 crew member placeholders and use them to create class objects
crew_members = [Person(str(i)) for i in range(12)]

# Print out the randomized value descriptions for each crew member
[print(str(i.get_sex) + ", " + str(i.get_education) + ", " +
str(i.get_height) + ", " + str(i.get_weight) + ", " + \

```

```
        str(i.get_detail)) for i in crew_members]

# Generate a plot and title
fig = plt.figure(figsize=(6.5, 6.5))
ax = fig.add_subplot(111)
ax.set_title("Crew Caloric Requirements per Month")

# Label axes
ax.set_xlabel("Months after take off")
ax.set_ylabel("Caloric In-take (1,000,000 kcal/month)")

# Set the length of the plot as well as the step
t = np.arange(0, 10, 1)

# Generate the y-values for each month and stores them
s_values = []
for num in range(len(t)):
    s_values.append(sum([v.nutrition_requirement("high", num) for v in
crew_members]))

# Plots the x-values and y-values on a plot
ax.plot(t, s_values)

# Sets the range of the y-axis of the graph and sets it to only use integers
ax.set_ylim(0, 1_500_000)
ax.xaxis.set_major_locator(MaxNLocator(integer=True))

# Creates a grid patten on the plot
ax.grid(axis="x", color="green", alpha=.3, linewidth=2, linestyle=":")
ax.grid(axis="y", color="black", alpha=.5, linewidth=.5)

# Shows the plot
plt.show()

# Store the list of consumption rates per month so it can be used
# for calories_left.py and calories_consumed.py programs
Consumption_rate = s_values

# Program 1 End
```

Program 2

```
# Astronauts Data Analysis# Astronauts
# Python
# Created in March 2021
"""
```

AstronautsDataAnalysis.py

Used to analyze and create probabilities for astronaut description for use in later test cases.

For the education level of the astronauts we are only going to consider their undergraduate because we don't need what they ended-up studying in particular, only their general knowledge. We'll only consider the astronauts that came after 2000 to stay as close to current trends as possible.

The data in the astronauts.csv file which is available in the Github [repository](#) was used in this program.

```
"""
```

```
# Imports
from random import randint
import csv

# List for counting sex-ratio of astronauts
s_lst = []

# List for degree percentages between men and women astronauts
me_lst = []
we_lst = []

# Degree categories list
category = ["Math", "Physics", "Engineering", "Chemistry", "Biology", "Other"]

# Sets comparison year(only after this year [up until 2009] will be considered)
year = 1995

# Opens up astronaut csv file that was imported from kaggle
with open("astronauts.csv") as csv_file:
    csv_reader = csv.reader(csv_file, delimiter=',')
    skip = True
    for row in csv_reader:
        if skip:
            skip = False
            continue
        if row[1] == '':
            continue
        if int(row[1]) > year:
            # Stores astronaut sex
            s_lst.append(row[6])
            if row[6] == "Male":
                # Stores male education
                me_lst.append(row[8])
            else:
                # Stores female education
                we_lst.append(row[8])

# Counts the number of men and women astronauts after the given year
number_men = s_lst.count("Male")
number_women = s_lst.count("Female")

# Converts the count to overall percentage score
```

```

percentage_of_men = str(100 * (number_men / (number_men + number_women)))[ :5]
percentage_of_women = str(100 * (number_women / (number_men +
number_women)))[ :5]

# Function to count the subjects that each sex studied and produce
percentages
def degree(lst):
    total_degree_number = 0
    degree_dict = {
        "Math": 0,
        "Physics": 0,
        "Engineering": 0,
        "Chemistry": 0,
        "Biology": 0,
        "Other": 0
    }

    for edu in lst:
        if "Math" in edu:
            degree_dict["Math"] += 1
        elif "Physic" in edu:
            degree_dict["Physics"] += 1
        elif "Engineer" in edu:
            degree_dict["Engineering"] += 1
        elif "Chem" in edu:
            degree_dict["Chemistry"] += 1
        elif "Bio" in edu:
            degree_dict["Biology"] += 1
        else:
            degree_dict["Other"] += 1
        total_degree_number += 1

    return [int(100 * (degree_dict[term] / total_degree_number)) for term in
category]

# Generates a random speciality based on the previous data and a given
astronaut sex
def degree_random(sex):
    per_lst = degree(me_lst) if sex == 'M' else degree(we_lst)
    tester = randint(0, 100)
    return "Math" if tester <= per_lst[0] else "Physics" if per_lst[0] <=
tester <= sum(per_lst[:2]) else "Engineering" \
    if sum(per_lst[:2]) <= tester <= sum(per_lst[:3]) else "Chemistry" if
sum(per_lst[:3]) <= tester <= sum(per_lst[:4]) \
    else "Biology" if sum(per_lst[:4]) <= tester <= sum(per_lst[:5]) else
"Other"

"""
For defining a height a weight, ranges will be extracted from the U.S Army's
height and weight screening
requirements for the time being (Military Standards for Fitness, weight, and
Body Composition). These estimations
are based on the assumption that the astronauts are fit. Conversion rates are
taken from the google calculator.
"""

# Generates a random height between height bounds for a specified sex
def height_random(sex):
    height_inches = (randint(620, 660) if sex == 'F' else randint(650, 720))
/ 10
    return int(height_inches * 2.54) / 100

# Generates a random weight between weight bounds for a specified sex

```

```
def weight_random(sex):  
    weight_pounds = (randint(128, 150) if sex == 'F' else randint(168, 206))  
    return int((weight_pounds / 2.20462) * 100) / 100  
# End of Program 2
```

Program 3

```
# Python
# matplotlib.pyplot is used to visualize the graph
# Figure 4 Program
# Kilocalories consumed by the crew
# during the spaceflight
# Created in March 2021
"""
```

calories_consumed.py

The output of the program below is showed in Figure 4 of the paper.
Used to visualize a graph that shows the amount of Kilocalories consumed by the crew during the spaceflight to Mars, considering Carbs, Proteins and Fat consumed.

```
"""
```

```
import matplotlib.pyplot as plt

timeInFlight = [0, 1, 2, 3, 4, 5, 6]

cal_consumed = [1045728.6293925, 1080586.25037225, 1045728.6293925,
1080586.25037225, 1115443.871352, 976013.3874329999,
1080586.25037225]

carbs = []
proteins = []
fat = []
fatty_acids = []
for i in range(len(cal_consumed)):
    calories_for_month = sum(cal_consumed[:i])
    carbs.append((0.45 * calories_for_month))
    proteins.append((0.35 * calories_for_month))
    fat.append((0.20 * calories_for_month))

print(calories_for_month)
print(carbs)
print(proteins)
print(fat)
print()

print(carbs[-1] / 4000)
print(proteins[-1] / 4000)
print(fat[-1] / 9000)

print(sum([(carbs[-1] / 4000), (proteins[-1] / 4000), (fat[-1] / 9000)]))

plt.xlabel('Months after take off')
plt.ylabel('Kilocalories Consumed (1,000,000 kcal)')
plt.title('Kilocalories Consumed by the Crew')
pal = ["#15ab00", "#ff1100", "#ff6600"]
plt.stackplot(timeInFlight, carbs, proteins, fat, labels=['Carbs',
'Proteins', 'Fat'], colors=pal)
plt.legend(loc='upper left')
plt.show()

# End of Program 3
```

Program 4

```
# Python
# matplotlib.pyplot is used to visualize the graph
# Figure 3 Program
# Kilocalories left for the crew
# Created in March 2021
"""
```

calories_left.py

The output of the program below is showed in Figure 3 of the paper. Used to visualize a graph that shows the amount of kilocalories left for the crew during and even after the spaceflight to Mars.

```
"""
import matplotlib.pyplot as plt

timeInFlight = [0,1,2,3,4,5,6,7,8,9]

cal_consumed = [1045728.6293925, 1080586.25037225, 1045728.6293925,
1080586.25037225, 1115443.871352, 976013.3874329999, 1080586.25037225,
1045728.6293925, 1080586.25037225, 1045728.6293925]

summ = 0
# The value of 7730 was found with the calculations in Table 8
production_list = [7730,7730,7730,7730,7730,7730,7730,7730,7730,7730]
sumList = []
for i in range(len(timeInFlight)):
    summ = 8000000 + sum(production_list[:i]) - sum(cal_consumed[:i])
    sumList.append(summ)

print(sumList)
plt.plot(timeInFlight, sumList)
plt.plot(timeInFlight, [0,0,0,0,0,0,0,0,0,0] )
plt.xlabel('Months after take off')
plt.ylabel('Kilocalories Left 1,000,000 kcal/month')
plt.title('Kilocalories Left for the crew per Month')
plt.show()

# End of Program 4
```

Program 5

```
// C++
// Created in March 2021
// This program calculates the BMI of an individual based on his weight and height
// and gives back a comment about their health and weight class according to the CDC
// guidelines

// bmi-range.cpp

#include <iostream>
using namespace std;

double BMI(double weight, double height);
void range(double BMI);

int main() {
    double weight = 0;
    double height = 0;
    double BMIum = 0;

    BMIum = BMI(weight, height);
    range(BMIum);

    return 0;
}

/*Calculates BMI using metric values*/
double BMI(double weight, double height) {
    double BMIum = 0;

    cout << "Enter weight (in kg): ";
    cin >> weight;
    cout << "Enter height (in m): ";
    cin >> height;
    cout << endl;

    BMIum = weight / (pow(height, 2));

    cout << "Your BMI is " << BMIum << endl;

    return BMIum;
}

/*Prints which range user is in*/
void range(double BMI) {
    cout << "According to CDC guidelines, you are: ";

    if (BMI < 18.5) {
        cout << "Underweight";
    }
    else if (BMI >= 18.5 && BMI < 25) {
        cout << "Normal";
    }
    else if (BMI >= 25 && BMI < 30) {
        cout << "Overweight";
    }
    else if (BMI >= 30 && BMI < 35) {
        cout << "Obese Class 1";
    }
    else if (BMI >= 35 && BMI < 40) {
```

```
        cout << "Obese Class 2";
    }
    else if (BMI >= 40) {
        cout << "Obese Class 3 (Severe)";
    }
    else {
        cout << "Error";
    }

    cout << endl;
}
// End of Program 5
```